STRUCTURAL EQUATION MODELLING OF CONSTRUCTION WASTE ROOT CAUSES AND WASTE GENERATION RATE IN MALAYSIAN CONSTRUCTION INDUSTRY

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SUAATHI A/P KALIANNAN

A thesis submitted in
fulfillment of the requirement for the award of the
Doctor of Philosophy

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MARCH 2021

DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged

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DEDICATION

Dedicated to the Lord,

Beloved father (Mr.Kaliannan Palaniandy), mother (Mrs. Meena Marappa) brother (Sarvana Kaliannan) and Sathiya Prakash Palen for their prayers and support

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ABSTRACT

Construction is one of the vital sectors in the economic growth, especially for a developing country like Malaysia. The rapid development of this industry is causing a huge amount of construction waste generated on site. Besides, illegal dumping of construction waste is quite a typical scenario in Malaysia which has been frequently published in the local newspapers and previous scholarly literature. Construction waste results from various causes which are necessary to be identified for reducing the waste generated in the construction project. Therefore, to overcome these problems, the root cause of the construction waste generation needs to be determined. The research aims to develop a structural relationship model between the root cause and waste generation rate for Malaysian construction industry. The quantitative approach, through a structured questionnaire survey is used to verify the root cause and determine the construction waste generation rate. A total of 321 questionnaire forms were received and analysed using factor analysis technique in SPSS software. The factor analysis resulted in 5 groups of root causes namely design and documentation, human resource, materials and equipment, project management and external. Furthermore, 12 types of material waste generation level were gathered through the questionnaire and the findings revealed that, timber and concrete waste are highly generated on site. Next, the relationship between the root causes of the construction waste and material waste generation rate was established using the advanced multivariate approach of the Partial Least Square-Structural Equation Modelling (PLS-SEM). It results that the performance of the model has a moderate explaining power ability with the value of $R^2 = 0.319$, which is substantial. The model identifies that all 5 groups are significant with t-value ≥ 2.58 from bootstrapping process. The model indicates that design and documentation group has the highest impact on the material waste generation rate. In addition, the model was validated and verified by construction experts where 94% of them agreed with the findings. Therefore, the model has the potential to aid the construction practitioners to reduce the construction waste generation in construction projects by focusing on the critical root causes established.

ABSTRAK

Pembinaan merupakan salah satu sektor penting dalam pembangunan ekonomi, terutamanya bagi negara yang sedang membangun seperti Malaysia. Perkembangan pesat industri ini menyebabkan sejumlah besar sisa pembinaan dihasilkan. Selain itu, pembuangan sisa pembinaan haram adalah senario biasa di Malaysia yang disiarkan di akhbar tempatan dan oleh penyelidik terdahulu. Sisa pembinaan terhasil akibat pelbagai punca dan amat penting untuk mengenalpasti punca-punca tersebut supaya dapat mengurangkan sisa pembinaan di tapak projek. Oleh itu, untuk mengatasi masalah ini punca penjanaan sisa pembinaan perlu ditentukan. Kajian ini bertujuan untuk membangunkan hubungan antara punca dan kadar penjanaan sisa pembinaan dalam industri pembinaan Malaysia. Pendekatan kuantitatif digunakan untuk menentukan punca dan kadar sisa pembinaan melalui soal-selidik berstruktur. Sejumlah 321 borang soal selidik diterima serta dianalisa menggunakan analisa pengfaktoran dalam perisian SPSS. Analisa pengfaktoran menghasilkan 5 kumpulan iaitu rekabentuk dan dokumentasi, sumber manusia, bahan dan peralatan serta luaran. Selanjutnya, 12 jenis sisa pembinaan mengikut peringkat penjanaan telah dikumpulkan dan mendedahkan bahawa kayu dan konkrit merupakan antara sisa janaan yang tertinggi di tapak pembinaan. Kemudian, hubungan antara punca janaan sisa dan kadar janaan sisa dihasilkan menggunakan pendekatan multivariat *Partial Least Square-Structural Equation Modeling* (PLS-SEM). Model ini, mempunyai keupayaan kuasa sederhana dengan nilai $R^2 = 0.319$. Model ini mendapati semua 5 kumpulan tersebut adalah signifikan dengan nilai $t \geq 2.58$ melalui proses *bootstrapping.* Didapati bahawa kumpulan rekabentuk & dokumentasi mempunyai impak yang paling tinggi terhadap kadar sisa pembinaan. Kemudian, model hubungan telah disahkan oleh pakar pembinaan dengan 94% telah bersetuju dengan kesahihan model tersebut. Oleh itu, model ini berpotensi untuk membantu pengamal pembinaan untuk mengurangkan penjanaan sisa pembinaan dalam projek-projek pembinaan dengan menyelesaikan punca yang kritikal.

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LIST OF SYMBOLS AND ABBREVIATIONS

AVE	-	Average Variance Extracted
BIM	-	Building Information Modelling
C&D	-	Construction and Demolition
CCC	-	Certificate of Completion and Compliance
CFR	-	Code of Federal Regulations
CFA	-	Confirmatory Factor Analysis
CIDB	-	Construction Industry Development Board
CITP	-	Construction Industry Transformation Programme
EFA	-	Exploratory Factor Analysis
EPA	-	Environmental Protection Agency
GDP	-	Gross Domestic Product
GLC	-	Government Linked Companies
JKR	-	Public Works Department
MWGR	-	Material Waste Generation Rate
PCA	-	Principal Component Analysis
PLS-SEM	-	Partial Least Square-Structural Equation Modelling
RORO	-	Roll-on Roll-off
SPSS	-	Statistical Package for Social Science
SWCorp	-	Solid Waste and Public Cleansing Management Corporation
UN	-	United Nation
US	-	United States
WRAP	-	Waste and Resources Action Programme
WGR	-	Waste Generation Rate

CHAPTER 1

INTRODUCTION

1.1 Research background

Construction sector is undoubtedly one of the key sectors leading to the pace of growth of the Gross Domestic Product (GDP) in any developing country (Pakhare, 2017). Besides, foreign and local investments in the construction industry have prompted employment prospects and contributed to the nation's economy. Consequently, the massive growth of this industry directly comes with a drawback which comes in the form of a huge amount of construction waste. Figure 1.1 illustrates that the sector is the topmost industry as consumers of raw materials. Nearly 3 billion tons of resources have been used each year in the construction industry.

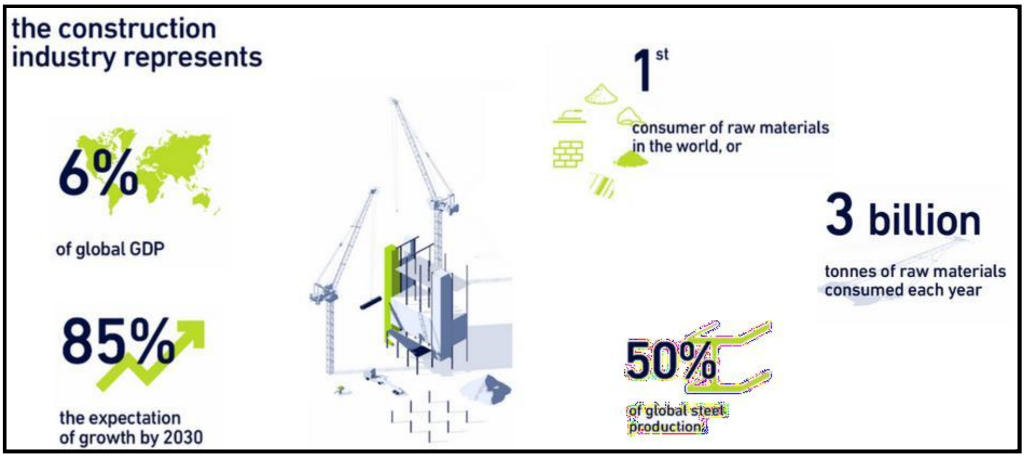

Figure 1.1: Global construction industry (Source: Worlds Economic Forum, 2018)

According to Figure 1.1, the global GDP is 6% and this industry is expected to grow to about 85% by the year 2030. Nearly 50% of the steel production in the world is in the construction industry. The volume of waste produced in this industry is immense due to the existence of building and construction activities for new developments for rapid urbanization, demolition and renovation (Poon *et al.*, 2013, Lachimpadi *et al.*, 2012 and Mah, Fujiwara & Ho, 2016). The construction industry uses 35% of produced energy and released 40% of carbon dioxide into the Earth's atmosphere. At the same time, the construction industry is the largest consumer of raw materials derived from natural resources (UN Environment, 2017).

In addition, the building construction process also produces material waste that negatively impacts the environment. The construction industry is using up a lot of resources, from the most regular material, sand, to profitable natural resources like timber (Poon *et al.*, 2004). The existence of the material on location, from its transportation and delivery, is carefully inspected, and unfortunately, there is a moderately large part of the materials being generated as waste as a result of poor material control on construction sites (Guerrero, Maas & Twillert, 2017). To reduce and manage these wastes, a comprehensive understanding of the root causes behind the construction waste generation is essential. Waste generation factors from construction activities vary depending on the size of the project, related activities, and the project location. The construction waste may already exist from the beginning of the construction process, such as site clearing, right through project handover.

Previous literature about the waste generation root causes in construction projects reveals that waste may occur from the outset starting from the design, construction and operation of the constructed facilities at any point of the construction process (Faniran and Caban, 1998, Fujiwara & Ho, 2016 and Saadi *et al.*, 2016). Furthermore, many companies in Malaysia do not have any specific policy to reduce waste and to establish a proper waste management plan. A decade ago, rapid construction and insufficient attention to C&D waste generation, particularly in developing countries like Malaysia has led to the immediate need for further research on area of waste generation (Begum *et al.*, 2007 and Saadi *et al.*, 2016). Therefore, detailed information about the construction waste generation and the root causes needs to be examined (Al-Rifai & Amoudi, 2016).

1.2 Problem statement

Malaysia's construction industry is noteworthy for the country's socio-economic development. It constitutes 3.9% to the overall Gross Domestic Product of the country (Bank Negara Malaysia, 2015). However, the acceleration and expansion in construction operations have resulted in a significant spike in the construction waste output (Mah *et al*., 2016). Nagapan & Rahman (2016) pointed out that the construction industry is facing severe problems due to the vast amount of construction waste generated in the country. Moreover, the Construction Industry Development Board of Malaysia (CIDB) stated that there are three critical issues that need to be addressed imminently and one of them is reducing the construction waste generation (Then, 2018). Besides, Michael (2018), has pointed out that illegal dumping is a serious issue and stiffer penalties need to be enforced.

Moreover, in Malaysia, there are no accurate data of construction waste streams and factors which cause the waste generation on-site (Begum *et al.*, 2007; Nagapan, 2014). A similar concern was also emphasized by some other researchers (Yuan & Shen, 2011; Lu & Yuan, 2011b; Azis *et al.*, 2012). In order to overcome this construction waste problem, CIDB started the Construction Industry Transformation Programme (CITP) 2016-2020 under environmental and sustainability thrust to carry out construction waste records for the country (CIDB, 2015). Furthermore, policy makers such as National Solid Waste and Public Cleansing Corporation (SWCorp) have initiated research works on construction waste quantification (SWCorp, 2016). Malaysia is aiming for zero construction waste by the year 2030 as reported by Chen (2015) and this was announced by the director of SWCorp.

To date, only a few researchers have studied the issues of construction waste in Malaysia such as on the illegal dumping (Rahim *et al.*, 2017), cost and time factors contributing to waste generation (Mah *et al.*, 2016), effect of construction waste to the environment (Nagapan, 2012) and construction waste recycling issues (Esa, Haloga and Rigamonti, 2017). Therefore, to envision the aim of CIDB and SWCorp, the root causes contributing to the waste generation and the waste generation rate have to be obtained. Thus, it is necessary to develop a hypothetical relationship model to visualize the correlation between the root causes and the waste generation rate. This aids the government to solve the root causes and the construction waste will indirectly be reduced. Hence, this research emphasizes on determining the root causes and waste generation rate of construction waste in the Malaysian construction industry.

1.3 Research questions

Grounded on the problem statement of this research, the research questions are articulated to assist the researcher to achieve the objectives. The research questions are as follows:-

i. What are the root causes of the construction waste generation rate in the Malaysian construction industry?

ii. What is the construction material waste generation rate in the Malaysian construction industry?

iii. How is a relationship model developed between the root causes and material waste generation rate?

1.4 Research aim and objectives

This study aims at developing a structural relationship model concerning the relationship between root causes and the generation rate of material waste for Malaysian construction industry. To that purpose, this thesis embarks on the objectives below:

i. To identify the root causes of the construction waste generation

ii. To determine the construction waste generation rate

iii. To develop a structural relationship model between root causes and construction material waste generation rate

iv. To validate the developed structural relationship model

1.5 Scope of research

Construction waste data collected in this study focuses the waste generated during construction only. Quantitative approach through a structured questionnaire survey is used to determine the root causes and the construction waste generation rate. This study only focuses on the material waste generated at construction sites. The targeted respondents chosen are contractors who are working at construction sites only as contractors are based at the site and deals with the construction waste generation. All the questionnaires were distributed throughout Peninsular Malaysia as this study was centered on the Malaysian construction industry. A relationship model is developed through Partial Least Square- Structural Equation Modelling (PLS-SEM) approach.

1.6 Significance of research

This study is aligned with the government's aim of Malaysia's Sustainable Infrastructure to be a blueprint for the emerging world and to have zero construction waste by year 2030 (Chen, 2015). Therefore this study is significant in developing a model to link the root causes of construction waste with the waste generation rate. Through this study, the crucial causes of the waste generation rate are identified and by the construction practitioners when they happen to encounter the issues. The developed structural relationship model aids the policymakers and the stakeholders in the construction industry to take note on the root causes which produce the most waste and the actions could be taken accordingly. In addition, the relationship between the root causes and waste generation rate is discovered and policy makers could incorporate the outcome of this study during development of guidelines and policies. The reduction of wastes from the construction have numerous benefits, including natural resource conservation and the reduction of the use of raw materials to produce construction materials. Hence, this study is significant in the sense that it benefits the construction industry, the environment and the betterment of the future.

1.7 Organisation of thesis

The organization of each chapter in the thesis is as follows:-

i. Chapter 1: Introduction - This chapter discusses the background of the research, the current situation and problem statement of this study. The objectives, scope and its significance are also highlighted.

ii. Chapter 2: Literature Review - This chapter elaborates, and discusses the previous studies done by other researchers focusing on the root causes of construction waste generation on site.

iii. Chapter 3: Research Methodology - This chapter illustrates the flow and method of research starting from the planning, until the implementation used, related standards and guidelines on the quantitative studies.

iv. Chapter 4: Data Analysis and Discussion - This chapter contains the overall result and discussions about the root causes and waste generation rate of the Malaysian construction industry. The data is analysed through SPSS.

v. Chapter 5: Structural Equation Modelling - A MWGR model was developed using the PLS-SEM approach and the results are discussed in this chapter. The MWGR model was developed for a better understanding of the practitioners and verified by the construction experts.

vi. Chapter 6: Conclusions and Recommendations - This chapter is about the overall conclusion of the study, goal achievement, and contribution to the body of knowledge as well as to the construction industry. The recommendations for further research are also included.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter 2 offers an overview of the construction waste generation. This chapter is written based on previous researchers' works and interpretations which are translated into a theoretical model. This model addresses the gap between the root causes and the construction waste generation rate in Malaysian construction industry. A relationship between the root causes of the construction waste generation and the rate of construction waste is established.

2.2 Definition of construction

Construction is a massive and competitive field of industry that plays a crucial role in the world economy (Behm, 2008). Construction work includes building structures, involving property acquisition tasks for selling as building sites or planning areas for potential development. Construction work involves modifications and upgrades including the installation, modification, or maintenance and repair of properties or development projects, such as highways or infrastructures. The definition of construction is presented in Table 2.1.

Table 2.1: Definition of construction

Num.	Concept of Construction	References
1	The building operations generally refer to several events, such as construction works, tunnelling, road works, bridges, and airfield.	Saadi *et al.*, 2016
2	Installation, alteration, relocation, deployment, commissioning, reconstruction, restoration, improvement, painting or other repairs, decommissioning, removal or destruction of a building.	Lawrence, 2016
3	Construction is defined as a process or a method of crafting, building or making something. Examples of construction works are roads, buildings, bridges, and so forth	Ashby, 2011

Therefore, in this study construction is defined as the process of development entailing the design work, installation, renovation, maintenance and repair.

2.3 Global construction industry

According to Timetric (2017), there was a steady pace of expansion in the global construction industry in 2016 which was 2.4%, but the next five years will undergo an improvement, with an average of 2.8% of growth. Asia-Pacific will have the largest share of the worldwide construction industry, of which India, Japan and China are the long-standing members. The global construction in 2030 would serve as the ultimate indication that the construction industry will hail as one of the most significant sectors of the global economy (Hermes, 2017). The construction industry will mark a primary profitable action that can expedite the progress of a developing country. This action has a lot to do with the rudimentary progress of infrastructure, technological interchange and improved contact to information networks (Haufler, 2013). Additionally, construction companies have increasingly been using the green construction techniques in the construction of energy efficient buildings and towards reducing the costs of the construction. Green construction constitutes the practice of using sustainable building materials and construction processes to create energy-efficient buildings with little environmental impact. Factors that spur the growth include greater population in emerging countries, better infrastructures in developed countries, alongside an increased rate of domestic development, and anticipated investments in the renewables and telecommunication domain (Meisels, 2018). The percentage of growth in the global construction industry shows a moderate increase, this can be referred to in Figure 2.1.

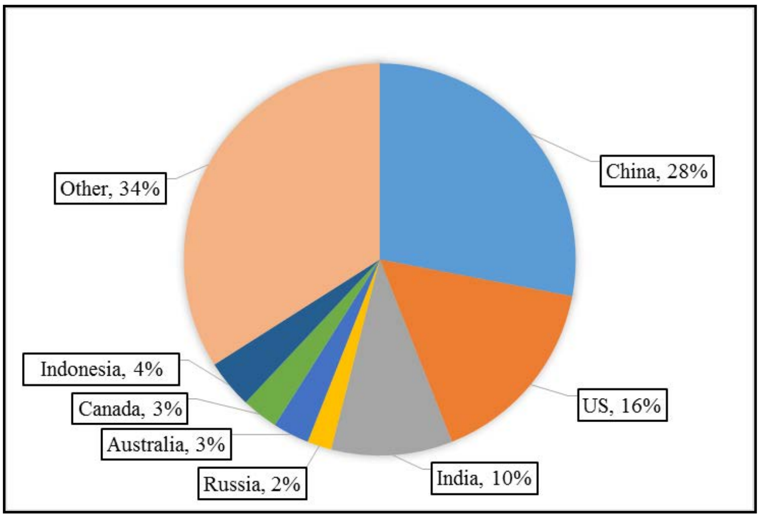

Figure 2.1: Percentage contribution to growth in global construction output 2010 - 2020 by country (Source: Muse, 2015)

In conclusion, in the next fifteen years construction is probably going to be one of the most dynamic industrialized sectors where it is absolutely pivotal to the making of prosperous societies globally. Furthermore, major economic growth together with lucrative financing deals backed by low interest rates in various developed and emerging markets is set to boost the global construction industry's average revenues. This contributes to the positive overall outlook on the construction sector.

Table 2.2: Mega construction around the world

Num.	Project	Estimated completion	Country
1	International Space Station (USD 150 billion)	2020	Russia
2	Industrial city Jubail II (USD 11 billion)	2024	Dubai
3	Beijing Daxing International Airport (USD 13 billion)	2025	China
4	California High Speed Rail (USD 70 billion)	2030	USA

There are numerous mega construction projects going on in the world as shown in Table 2.2. The construction industry has matured over the last decades and resulted in enhancements in company profits, financial convenience and increased commodities in many countries (Nadhim, 2016). Therefore, most of the countries have started to focus on mega project developments and this will cause unnecessary construction waste generation problems.

2.3.1 Global construction waste in construction industry

i. China

With its impressive development for years to come, the construction industry of China is required to proceed. To date, major scale urban development programs, especially the wide urban restoration programs in metropolitan cities, have caused great construction waste and remarkable ecological effects (Li *et al.*, 2017). A report from National Development and Reform Commission of China stated that China produced five times more construction waste in 2013 than the measure of municipal waste created in China in a similar period. Nonetheless, little of the construction waste was recycled or reused (Duan, 2016). A clear case of this prediction happened in Shenzhen, China, where a pile of construction waste collapsed five years ago (Xu *et al.*, 2015). The landslide had ravaged three dozen structures and contributed to the missing of 85 individuals, who were later found from the rubbles of the construction waste. This circumstance shows that with significant urban advancement all through the nation, China had to face enormous difficulties for overseeing its construction waste.

ii. Indonesia

For the past decade, research that have looked into the construction waste has been crucial in Indonesia. Previous literature revealed that there has been concern of the abnormally high state of waste inside the Indonesian construction venture and the waste can influence the development progress execution (Elizar *et al.*, 2015). Indonesia's legislature has various programs with specific end goals to expand the economic growth. This program should have been supported by a proper waste administration framework (Prajati *et al.*, 2017). No practical or adequate technique has been settled upon by all gatherings linked with construction undertakings to lessen the construction waste. As an example, Indonesia, serves to be a country that has yet to practice recycling innovation (Sumarjono *et al.*, 2012 and Elizar *et al.*, 2015).

iii. India

Indians have become so used to seeing massive heaps of construction waste, piled nearby the road shoulder, affecting both the traffic and the drains (Singh, Raju and Shravan, 2018). Caused by the rapid progress of the construction, about 30% of the entire waste has been created in India (Kumar *et al.*, 2017). If actions in the construction waste management are not properly formed and applied, the risk will surely be on the environmental circumstance and also affect the country’s sustainable development (Shrivasatava & Chini, 2009). It is crucial to minimise and handle construction waste if the limited landfill space and of the increasing amount of construction waste are to be considered, or issues identified might arise when dealing with the waste and determining a landfilling area.

iv. United States of America (USA)

Most construction waste in the U.S. at present is bound for disposal in landfills legitimately under Code of Federal Regulations (CFR). All or part of the construction waste stream is unlawfully disposed on land, or in drainage including water, unlike the control to ensure human wellbeing, also to ensure that it does not harm commerce and nature (Napier, 2016). Costa Rica is a developing country of Central America with nearly 4.9 million population. More than half of the total population live in urban areas. The contribution of the construction industry to the Gross Domestic Product over the most recent five years is quite high. This shows the significance of this area in the economy of the nation. Some research works have discovered that the construction waste generation extends about 700 kg/m2 (Abarca-Guerrero *et al.*, 2017).

v. Australia

Hyder (2011) stated that in Australia, a total of 19.0 million tons of construction waste had been abandoned back in the year 2008-2009. Out of the total waste output, 8.5 million tons of garbage were disposed at the landfill, whereas 10.5 million tons (55 percent) were collected and processed (Zakar, 2009). Construction waste treatment keeps being improved year to year, however its volume grows each year as the waste reduction and minimization have not changed much (Li *et al.*, 2013). In Australia, concrete, bricks, asphalt, dirt, wood and ferrous metals are among the most critical and the widely recycled construction waste stream components, as they always come in bulk and they have an expanding market for recycling and recovery, or a significant economic value (e.g. metals) (EPHC, 2009).

vi. Turkey

Construction industry in Turkey plays its part as one of the main driving forces for the entire economic growth. Besides, Turkey is a country that is prone for natural disasters, especially earthquakes (Arslan *et al.*, 2012) where 66% of the land is in the first and second level earthquake zone altogether reflecting almost 71% of the country's populace. As it is, the development must be transformed through quick demolition and reinforcement activities considering the great earthquake risk (Polat *et al.,* 2017). The construction wastes are then recycled and the remaining materials will be sent to the landfills by the contracting firm (Ulubeyli *et al.*, 2017 and Kose *et al.*, 2007). For the record, recycling has been commonplace in Turkey since 2006 (Ajayi, 2017).

vii. Malaysia

Construction industry in Malaysia helps spur the socioeconomic development of the country, where it contributes 3.9% to the overall Gross Domestic Product of the country (Bank Negara Malaysia, 2015). The growth in the Malaysian economy would be expected to increase to between 4.3% and 4.8% in 2017 and 5.0% to 6.0% in 2018 (CIDB, 2017), the expansion of development activities has led to a significant rise in the construction waste production (Mah *et al.*, 2016). Nagapan & Rahman (2016) further indicated that due to this, the construction industry was experiencing severe problems. Regrettably, there are no accurate data with regard to the evidence on construction waste in Malaysia and the reasons behind waste production in any given site (Begum *et al.*, 2007; Nagapan, 2014 and CIDB, 2017).

In order to address this issue, the Construction Industry Development Board of Malaysia (CIDB) had launched the Construction Industry Transformation Programme (CITP) 2016-2020 to perform the construction waste records for the country (CIDB, 2015). As the next step, policymakers such as National Solid Waste and Public Cleansing Corporation (SWCorp) have initiated research works on construction waste quantification (SWCorp, 2015).

2.4 Malaysian construction industry

In a fast-paced world, the construction industry in Malaysia has played a very significant role in its economic growth (Behm, 2008 & Nagapan and Rahman, 2012). Over the past two decades, the industry has been continuously contributing 3some percentage to the national GDP (CIDB, 2014). However, the industry has its shortcomings. Challenges in terms of the productivity, quality, safety, technology and unproductive practices have to be answered to. The government is seeking to elevate the country, by pushing forward, which has a key aim of launching into a comprehensive quantum leap towards a knowledgeable society. The Malaysian economy is expected to demonstrate a constant growth that is between 4.3% and 4.8% for 2017, and 5.0% to 6.0% for 2018 (CIDB, 2017). Domestic demands will be the primary catalyst of growth, and the private sector activity will be leading ahead. With new and existing civil engineering projects, the construction sector will continue to develop. There is an estimation of a viable demand at RM170 billion for 2017 and RM180 billion for 2018 in the construction sector. Next, the sector then continued to nurture at 8.0% for 2017 and escalated further to 10.3% for 2018 (CIDB, 2017).

Table 2.3: Construction projects registered under CIDB (Source: CIDB, 2018)

Sector	Num. of Project			
	2014	2015	2016	2017
Private Sector	6175	5140	5847	5499
Government sector	1764	1745	2097	2099

Table 2.3 shows the number of initiatives in Malaysia from 2014 to 2017. As per Malaysia's eleventh program, the government has given top priority to construction industry research and development as one of its key sustainable development strategies. The vital effect of Malaysian development projects comes from the implementation of 24 massive projects worth more than RM1.0 billion each. In 2016 these initiatives totaled RM109.9 billion (CIDB, 2017). The 5 major projects included:

i. Mass Rapid Transit Sungai Buloh – Serdang – Putrajaya Line (Jalan Ipoh North Escape Shaft to Desa Waterpark South Portal) in Klang Valley. Awarded: March 2016; expected to complete: 2021
ii. Electrified Double Track (Gemas to Johor Bahru) in Johor. Awarded: October 2016; Expected to complete: 2020
iii. Combined Cycle Gas Turbine Power Plant in Alor Gajar, Melaka. Awarded: November 2016; expected to complete: 2021
iv. Setiawangsa – Pantai Expressway in Kuala Lumpur. Awarded: November 2016; Expected to complete: 2020

2.5 Construction process

There has been a systematic planning for the construction projects, from the tendering stage up to the building hand over stage. The processes of construction began from the pre-design phase, design phase, construction phase and post-construction phase (Mehta, Scarborough & Armpriest, 2012), all of which are explained below:

i. Planning phase

The development is defined with regard to the scope, purpose and economics (Mehta *et al.*, 2012). This planning phase is the most important of all the construction phases, as the success of the project totally depends on the proper plan of the phase and the management of the phase (Zwikael, 2009). Construction planning and managing sheds light on creating the right sequence and performance of activities in the project execution (Gibson, 2012). This phase entails the tendering process, conceptual design, cost estimation and site investigation (Bakshan *et al.*, 2015).

ii. Design phase

Design development takes the outlines that have been agreed upon in the planning phase and they are then developed further. It is one of the most substantial phases for all major design components of the project (Minikevicius, 2016). Having developed and defined all the necessary details, all the critical design decisions are made and agreed upon by architects, clients and consultants in the final phase of the work. A project schedule has to undergo three crucial phase before it is to proceed- it should be developed, reviewed, and approved by the necessary regulatory agencies of the government bodies (kemper, 2015). By the end of this phase, the construction drawings and specification must be able to be finished (Mehta *et al.*, 2012).

iii. Pre-construction phase

In the pre-construction phase, the site team consisting of engineers, supervisor, also a project manager has to be established (Minikevicius, 2016). In this phase where the procurements will be coordinated, stocking up materials and equipment must also be done at this point (Panfilova, 2017). The purchasing is done according to plan prior to the construction phase. Labour supply is also managed in this stage before any construction work is to begin.

iv. Construction phase

The construction of a structure entails multiple specific skills where the work cannot typically be accepted by a particular construction company (Mehta *et al.*, 2012). Instead, the labor is commonly completed by a line of experts who have to look into, and be responsible for, the building's design and function, as well as the materials used including the materials used for site excavation, underground services installation, steel erection, concrete pouring, roofing, framing, exterior and interior work, etc (Panfilova, 2017). Every single stage is examined by the project manager and a government construction assessor. When the construction progress is completed, only then that the phase would have been considered as finished.

v. Post-construction phase

Prior to the completion, the damage caused by installation or use of temporary work must be attended to, where it shall be cleaned and repaired. All existing facilities in the construction should be restored to their original condition (Zwikael, 2009). In addition, the Certificate of Compliance and Completion (CCC) primarily indicates that the building is now safe for use (Zakaria, Ani & Ali, 2014). CCC issuance would have to cater for specific requirements set by the authorities. These requirements include submitting the building plans for approval, supervising the construction, also ensuring the compliance with the technical conditions enacted by the local authority and they have to be carried out (Dahlan & Hilal, 2013).

2.6 Definition of waste

The term waste originates from a Latin word 'vastum', meaning "land which was either not usable, not cultivated or not taxed" (Koskela, Sacks and Rooke, 2012). Waste was a legal term in communal law, and to a certain extent it is comparable to the notion of destruction (Blackstone et al. 1827). The conception of waste became well established among scholars and professionals in the early 19th century. It can be considered as the expense of laboring force to address the conflicts which is necessary owing to physical or mechanical occurrences, but which does not produce any value or expense of time, or waste of the prospective laboring forces (Koskela, Sacks and Rooke, 2012). Waste in the construction industry has been the cause for concern among several research projects all over the world.

Table 2.4: Definition of waste

Num.	References	Definition
1	Formoso *et al.*, (1999)	Waste in the unnecessary costs that result from inefficient practices, system or controls.
2	Hollander (1998)	Waste is something that needs to be expelled in order that the system continues to function.
3	Pongracz & Pohjola (2004)	Waste is what we do not want or fail to use.
4	Oteng-Ababio (2014)	Wastes are substances or objects which are disposed or are intended to be disposed or are required to be disposed by the provisions of national law.

The various concepts of waste are shown in Table 2.4. Some of them focus on the environmental damage that results from the material waste generation. Wyatt (1978) and Formoso et al., (1999) stressed on the consequences of high levels of waste in reducing the future availability of materials and energy, and creating unnecessary demands on the transportation system. Basically, waste can be anything that we are throwing away. Even if the substance is given to someone else to be reused or recycled, it is still legally considered to be waste if it is no longer required by the individual who creates or owns it.

2.6.1 Construction waste

Construction waste is consequential in many countries as it tends to defy the performance of the industry and the sustainable aims. Construction waste may be initiated at any phase of the construction practice, and its origins may be unfolded in the design decisions, the technique of construction or with the behaviour of the people (Kulatunga *et al.*, 2006). The nature of construction itself supports the generation of waste as well as obstructs the implementation of waste management practices. Existing construction wastes are solid waste produced from construction, demolition and land clearing activity (Asgari *et al.*, 2017). Waste in construction does not only focus on the quantity of waste on-site but also related to activities such as overproduction, waiting time, material handling, processing, inventories and movement of workers (Nagapan *et al.*, 2012). According to Begum *et al.* (2010) and Rahim *et al.* (2017), the construction waste generation has been increasing every year in Malaysia. The various definitions of construction waste are shown in Table 2.5.

Table 2.5: Definition of construction waste

Num.	References	Definition
1	Jain (2012)	Activities such as construction, renovation or demolition of structures generate an inert and non-inert material defined as construction wastes.
2	Tam *et al*. (2007)	Construction waste is defined as any unwanted products from the construction, renovation and demolition works.
3	Wrap (2006)	The construction, renovation and demolition activities which generate waste; the excess or damaged products during construction work; and temporarily products used during the activities are called as construction and demolition waste.
4	Lu & Yuan (2011)	Any waste or damaged materials generated from construction, renovation and demolition activities.
5	Nagapan *et al*. (2012)	Materials with no remaining value.
6	Muhwezi *et al*. (2012)	Any material that needs to be recycled or reused other than a particular purpose project because of damages, excessive, non-use, or noncompliance with the specifications needed.
7	Tam & Wu (2016)	Waste materials, which are not just rubbish and unwanted materials, but also includes excavated materials.
8	Chen & Lu (2017)	Construction waste, is defined as the surplus and damaged products and materials that arise from construction, renovation, demolition, and other construction activities.
9	Menegaki & Damigos (2018)	Material, including inert waste, non-inert non-hazardous waste and hazardous waste, generated from construction, renovation, and demolition activities.

Most of the construction wastes are recyclable and reusable, but the waste are usually dumped in the landfill (Shen *et al.*, 2004).Thus, it can be concluded that construction waste can be defined as any material that are solid, unwanted, damaged and unused at a construction site.

2.6.2 Types of construction waste

There are many types of construction waste such as timber, concrete, bricks, metal, packaging waste, tiles, glass, soil, aggregate, plastic material, asphalt, cardboard, gypsum board and mixed waste. The literature can be found in Table 2.6. Construction wastes are more substantial, more massive and on circumstances more toxic than local waste (Ponnanda, 2015). In a few occurrences, the contractor resorts to an improper or even an unlawful practice, for example, (i) unlawful dumping in abandoned territories; (ii) hiding trash in lush or forested zones; (iii) blending with household waste; (iv) covering in surrendered locales; (v) dumping in conduits; and (vi) burning (Sapuay, 2016).

Table 2.6: Types of construction waste

References	Types of waste											
	Timber	Concrete	Brick	Metal	Packaging material	Tiles/ ceramic	Glass	Soil/ aggregate	Plastic	Asphalt	Cardboard	Gypsum board
Gavilan, and Bernold, (1994)	x	x		x	x	x			x			
Hurley (2003)	x	x	x	x	x	x		x	x	x		
Mydin, Kohr* Sani (2014)	x	x	x	x	x	x		x	x	x		x
Lau, Whyte & Law (2008)	x	x	x	x	x	x		x	x	x	x	x
USEPA (2017)	x	x	x	x	x	x	x	x	x	x	x	x
Saez, Amores & Rio Merino, (2015)	x	x	x	x	x	x		x		x		
Lachimpadi *et al.*, (2012)	x	x	x	x		x		x		x		
CIDB, 2017	x	x	x	x	x	x	x	x	x	x	x	x

As seen in Table 2.6, almost all researchers have mentioned about timber, concrete, brick, metal, tile, packaging waste, plastic and asphalt as types of construction waste.

2.7 Root causes of construction waste generation

Construction waste is created from the very start, to the very last stage of the construction. Numerous factors have been found to contribute to this. It is undoubtedly essential to distinguish those causes so that waste generation can be curbed at the source. Most of the construction waste is produced during the design and construction stage because it is at this stage that the waste production is higher. For instance, a specific type of construction materials uses a considerable quantity of non-sustainable resources of energy, for example, timber, sand, and crushed stone (Formoso *et al.*, 2003). The root cause, if corrected would prevent same issue from recurring whereas causes mean a condition or event resulting in a problem as mentioned by Rausand (2004). Thus, in order to lessen the construction waste the root causes need to be identified to avoid the repetition of the same issue. According to Nagapan *et al.*, (2012), there are several root cause factors of construction waste generation in terms of the design, workers, management, procurement, site condition, handling and external factors. 80 root causes were identified initially as in Appendix A; then, they are grouped into physical waste and non-physical waste. In this study, only physical waste was accounted for, as the relationship between types of material waste generation and root causes was developed towards the end of this study. Next, the grouping of physical waste has reduced the root causes to 52 and they were incorporated in the pilot survey. They are identified from the previous literature which is explained as follows:-

2.7.1 Supervision during construction stage is poor

Good, well-planned supervision and coordination are clearly expected to guarantee excellent task conveyance. Satisfactory supervision will produce quality employment yet incurs extra cost for the successful supervision (Adewuyi & Odesola, 2015, Chandrasekar & Nigussie, 2018). Project supervision concerns with the checking, evaluative audit, detailing, and technical activities to be able to distinguish the project challenges, ascertain, plan and propose the solution in a conceivable time (Dalibi, 2016). Proper project supervision amid the construction stage is imperative as it enables relevant parties to troubleshoot or have some idea of the different elements that may cause structure collapse; a ton of activities will not go unnoticed, unchecked, un-affirmed and not complying with the specifications or guidelines if the supervision is well carried out (Wang *et al.*, 2008 and Polat *et al.*, 2017). For example, when the supervisor is not competent enough do the supervision of the work, error is most definitely going to occur and as the result, the constructed area has to be altered during inspection. Reversibly, inadequate supervision on site can lead to more generation of waste for materials such as concrete, timber and metal.

2.7.2 Efficient site management is lacking

Site management should have a work task flow that complies with the project's needs (Ajayi, 2017 and Lu *et al.*, 2011). Staff teamwork should be incorporated to ensure efficient site management plan (Al-Fadhali *et al.*, 2018 and Polat *et al.*, 2017). Managing the scope, issues, risks, communication and the work plan are all included as the tasks that have to be addressed by the team. If the management on site is not systematic, it is very like that the work done will be faulty and the next thing that can be expected is reworking (Saadi, Ismail & Alias, 2016). If the necessary management is lacking, the construction waste generated will not b efficiently coordinated, thus massive amount of waste will not be reused or recycled and instead, they will not be used and will go to waste. This root cause is one of the main factors behind the construction waste generation.

2.7.3 Last minute changes due to client requirements

Changes in design that take place during the construction is another root cause that can yield waste (Olusanjo *et al.*, 2014, Poon *et al.*, 2004). The amendment is done following the client's last minute requirements. This change can further contribute to physical waste (Polat *et al.*, 2017 and Osmani *et al.*, 2008). Clients should be clear with project vision from the beginning so that future or potential generation waste can be avoided. For instance, the relocation of windows or doors needs to be hacked due to client's last minute request or instruction, thus automatically, be it with intention or otherwise, this will generate material wastage.

2.7.4 Cutting uneconomical sizes of materials

Wastage can also happen when the materials are cut into different sizes and uneconomical shapes. (Polat *et al.*, 2017 and Ajayi, 2017). For example, timber or metal is simply cut without considering if it can be used in any way in the future; thus, the excess becomes waste. Workers should acknowledge the potential use in the future to manage the material accordingly. Material leftover from cutting shows that the systematic material management on-site is inadequate (Hassan *et al.*, 2015). This is one of the most significant weaknesses in waste production (Bekr, 2014 and Nikmehr *et al.*, 2015). Waste is produced from cutting different sizes of timber for a particular space creating a lot of small leftovers that cannot be reused and this is, of course, another form of waste.

2.7.5 Constant design changes during construction period

This issue happens as there have been sudden drawing changes amid the construction activities going on (Choudhry *et al.*, 2017, Lu *et al.*, 2011 & Adewuyi, 2015). This will become troublesome to the contractors, designers and the clients during the work stage design (Polat *et al.*, 2017, Bekr, 2014 & Olusanjo *et al.*, 2014). The design should be approved first during the preliminary stage to mitigate frequent changes during the construction period that can lead to material wastage. To avoid repeated design changes a complete response from similar projects needs to be considered and consulted (Abusafiya, 2017). This would be easier if the industrial players involved have a frequent productive meeting during the design stage to confirm the design before the construction actually starts

2.7.6 Unsuitable tools used during construction stage

As another thing to remember, the tools used for the construction work should be appropriate according to how it is used in the project at hand. Tools used by workers during construction are not appropriate or suitable for a certain type of civil works (Arshad *et al.*, 2017, Wang *et al.*, 2008 and Tam *et al.*, 2007). For example, using a small vibrating poker for a large area of concrete will definitely reveal bad workmanship, thus it needs to be hacked and the work rectified or even redone. This process will definitely lead to the construction waste generation.

2.7.7 Unsatisfactory attitudes of workers

In a construction site, poor behaviour can cause a headache to everyone and cause workers to feel unhappy and dissatisfied (Saadi *et al.*, 2016 and Nadhim *et al.*, 2016). Workers' laziness can make a project have to be done twice. Hence bad attitude may cause other workers to become dispirited and unhappy, automatically leading to more mistakes and poor output (Phakare, 2017 and Hamedani, 2012). For instance, workers' poor attitude will make them disoriented, lose focus on the work, thus potentially the output will be faulty and the work has to be done again. It is probable that this will generate concrete, timber, metal and brick waste.

2.7.8 Late information flow among all parties involved in the project causes redundant of work

Communication and effective information flow is pivotal in construction procedures (Hassan *et al.*, 2015 and Polat *et al.*, 2017) due to the fact that the planning related or material streams can exist without proper information flow. Having an efficient information flow among all parties is set to give a a construction project focused favourable advantage via lower costs, improved client administration, and more effective business procedure (Memon and Rahman, 2014, Akhir, 2015 and Osmani *et al.*, 2008). Bad information flow is the reason behind work redundancy. For example, when a piece of information is still not informed to the site team, they will have to supervise their progress, thus, the work progress will be done using the existing design hence, upon receiving the information, it might be a little too late and everything must be redone. As a whole, the rectification work can produce more wastage in the construction industry.

2.7.9 Improper way of material handling by the workers

The unpacking and arrangement of materials should be done properly to avoid any damage (Nikmehr *et al.*, 2015, Adewuyi, 2015, Polat *et al.*, 2017,). If the material is not handled meticulously, damage can occur and further generate construction waste (Dalibi, 2016). Significant material losses were caused by materials being unloaded incorrectly. For example, unloading bricks by having them thrown from one place to another will damage the bricks and this will be wasteful. This is possibly due to the workers' laid-back and careless attitudes when handling the materials (Bekr, 2014 and Polat & Ballard, 2004).

2.7.10 Rework due to miscommunication among engineers and workers

Communication failure can ultimately lead to serious accidents on site, project rework, and employee problems (Bekr, 2014). When there is team miscommunication, rework will occur often and material waste will be yielded. Effective communication among team members would be very important for collaborative work (Abusafiya & Suliman, 2017 and Polat & Ballard, 2004). Clear communication not only reduces the possibility of rework, but it can also increase the efficiency of the construction process significantly (Polat *et al.*, 2017 and Olusanjo *et al.*, 2014). Misunderstanding and miscommunication on site will further lead to the generation of material waste because the work has to be dealt with again and again.

2.7.11 Lack of possibility ordering small quantity of materials

According to Guerrero (2014), the lack of possibility in ordering small quantity of materials is one common cause of construction waste generation. Usually, only bulk orders can be ordered from a supplier (Adewuyi *et al.*, 2015, Muhwezi *et al.*, 2012 and Kulatunga *et al.*, 2005). There would be minimal ordering amount to be fulfilled despite the fact that the amount required is less than the minimum order. With that, material waste will exist if there are too many materials unused.

2.7.12 Lack of coordination among parties involved in the project

According to Alaloul *et al.*, (2016), the coordination among all parties involved in a project is vital to ensure a successful implementation of all construction phases. Coordination is critical among similar parties in a project, and among various groups throughout the project (Dalibi, 2016, Nazech *et al.,* 2008 and Yun peng, 2011). It will give the construction field a greater adaptability to fit with the dynamic condition. Lack of coordination may indirectly lead to the waste generation in the construction industry (Ajayi & Oyedele, 2018, Haile & Hartono, 2017 and Alwi *et al.*, 2002). For example, amid the poor staff coordination, confusion and errors might be inevitable, thus waste such as bricks, tiles, glass, timber and concrete will be produced.

2.7.13 Improper construction methods applied by the workers

Construction methods stand to be the mainstay of a site organization as they are laid out in the form of the construction plan. It is crucial to improve the construction methods constantly throughout the construction period (Dajadian & Koch, 2014 and

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